East Asian Latecomer Firms: Learning the Technology of Electronics

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Summary. — This paper introduces the idea of the latecomer firm to explore how the four dragons of East Asia (South Korea, Taiwan, Hong Kong and Singapore) learned to innovate in electronics. The paper examines the historical progress of technological development and sets out the institutional mechanisms by which firms acquired foreign technology. Using one case study from each country, the paper explores how East Asian firms learned process and product skills and know-how. Within the firms, subcontracting and original equipment manufacture (OEM) mechanisms acted as a training school for latecomers, enabling them to overcome entry barriers and to assimilate manufacturing and design technology. The needs of export customers drove the pace of learning and acted as a focusing device for technological assimilation, adaptation and innovation. To interpret the findings, a simple model of how latecomers linked their technological learning to export markets is put forward. In contrast with the research and development (R&D) and design-led strategies typical of leaders and followers, latecomers began with incremental improvements to manufacturing processes which led on to minor product innovations. The evidence suggests that the origins and paths of the East Asian latecomers continue to influence their strategies, structures and technological orientations.

1. INTRODUCTION

The newly industrializing economies (NIEs) or “dragons” of East Asia (South Korea, Taiwan, Singapore and Hong Kong) have become formidable competitors in electronics. Compared with Japan, the four are genuine latecomer economies, having little industrial history prior to the 1950s.1 The electronics sector has played an important part in each country’s economic progress.2 During the 1980s electronics became the largest, fastest-growing export sector in East Asia, contributing to industrial output, employment and technological development.

The general economic and industrial achievements of the dragons are well known. Less well understood are the strategies by which firms acquired foreign technology and learned to innovate in particular sectors.3 The purpose of this paper is therefore to explore how local East Asian firms overcame barriers to entry and learned the technology of electronics. To interpret the findings, the paper tries to relate the patterns of corporate learning to conventional Western models of innovation.4 Although the study focuses on electronics, it recognises that the paths and patterns of technological learning will differ from sector to sector.

In the literature on East Asian industrialization, relatively little attention has been paid to the technology strategies of manufacturers. The classic studies of technological learning by Dahlman, Ross-Larson and Westphal (1985) and Westphal, Kim and Dahlman (1985) tend to examine general technological processes rather than the firm-level experiences and strategies.5 In general, there is little research into non-Korean East Asian companies, although there is a growing literature on the question of macroeconomic performance and the role of governments in guiding industrialization.6 An understanding of company technology strategies is also important, as firms are the locus of competitive performance, exports, and productivity growth in East Asia, as elsewhere.

Section 2 introduces the idea of the latecomer firm to describe the technological difficulties confronting East Asians wishing to compete in international markets. Section 3 looks at the broad historical evidence to show the phasing of technological development in the four dragons and the resulting technological strengths and weaknesses of electronics firms. Section

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4 summarizes the chief institutional mechanisms by which local companies acquired foreign technology.

Section 5 provides insights into how East Asian latecomer firms accumulated process and product skills and knowhow through learning. It explores the paths and patterns of technological learning in four firms, one from each NIE. The purpose is to provide a qualitative view of company learning strategies and mechanisms to complement the historical analysis. Section 5 pays special attention to how learning proceeded under subcontracting and original equipment manufacture (OEM) arrangements with foreign buyers and transnational corporations (TNCs). Section 6 puts forward a simple model of how latecomer firms linked their technological learning to export growth. It also highlights further questions regarding the strategies, structures and orientations of latecomer companies. Section 7 asks whether there are any general lessons for other developing countries.

2. THE EAST ASIAN LATECOMER FIRM

For the purposes of this paper a latecomer firm is defined as a manufacturing company (existing or potential) which faces two sets of competitive disadvantages in attempting to compete in export markets. The first is technological in character. Located in a developing country, a latecomer is dislocated from the main international sources of technology and research and development (R&D). It operates in isolation from the three world centers of science and innovation and is behind in engineering, technical skills and R&D. Its surrounding industrial and technological infrastructure is poorly developed. Universities may be weak technologically and other educational and technical institutions poorly equipped.

Normally, access to technology and a healthy surrounding national system of innovation is assumed to be essential for corporate competitiveness (Nelson and Rosenberg, 1993). To succeed in international markets, the latecomer firm must overcome these technological disadvantages.

The second disadvantage concerns leading-edge markets and demanding users. To add to its technological difficulties, the latecomer firm is dislocated from the mainstream international markets it wishes to supply. These are located in the advanced countries. Typically it will confront underdeveloped, small local markets and unsophisticated users. Many studies show the importance of user-producer linkages and clustering to innovation and industrial development. To succeed, the latecomer company has to devise ways of overcoming market barriers to entry and then to forge the user-producer linkages which stimulate technological advance. Based in a developing country, the latecomer has to develop outside the major international clusters of innovative suppliers and users.

Latecomers are clearly different from leaders. Technology leaders generate new products and processes to gain advantages in the marketplace. Unlike a latecomer, a leader typically has a large R&D department capable of generating new innovations and contributing to the world technology frontier and its own competitive edge. A leader may also enjoy strong and useful connections with universities and other parts of the surrounding technological infrastructure (e.g. IBM and Intel in the United States).

Latecomer firms are also distinct from technology followers who, like leaders, are connected directly into the advanced markets in which they serve. Indeed, in some circumstances, fast followers may have advantages over leaders. They will have substantial technological resources to learn rapidly from the leader’s experience, to avoid some of the R&D costs through imitation, and to adapt a product or process more closely to a buyer’s need. For example, Fairchild was the leader in the eight-bit microprocessor, but it lost its lead to followers Zilog, Intel and Motorola who introduced improvements to the basic Fairchild design (Langlois et al., 1988, p. 115).

Leader and follower advantages are not presented to latecomers because they are weak technologically and isolated from advanced users. As shown below, however, latecomers have substantial cost advantages, and this can form part of their initial market entry strategy. The overall challenge confronting the latecomer is how to devise and implement corporate strategies which enable them to overcome initial market and technological barriers to entry, to systematically build internal capabilities and to increase export sales.

Very little is known about how latecomer firms from the NIEs overcame these disadvantages, forged inroads into advanced markets, conducted their rapid catch-up learning and, in some areas, overtook traditional leaders. Some studies show how Japanese firms managed their entry into foreign markets (e.g., Abegglen and Stalk, 1985). Unlike the four NIEs, however, Japan had a relatively long history of industrial development prior to the 1950s and 1960s. By contrast, the four dragons, especially Taiwan and South Korea, were very poorly endowed in the 1950s and had little absorptive capacity.

3. HISTORICAL PHASING OF TECHNOLOGY DEVELOPMENT

This section uses selective historical evidence to show the phasing of technological progress in electronics. The evidence suggests that progress occurred gradually and that a variety of mechanisms were utilized by latecomer firms to link their technological acquisition to export markets. As section 4 shows, foreign TNCs and buyers played an important role in stimulating the advances of the latecomers.
Each of the dragons has made considerable progress in electronics since the 1960s and especially during the 1980s. In Hong Kong, for instance, exports of electronics increased more than threefold from US$2.8 billion in 1981 to around US$7.5 billion in 1990. South Korean electronics exports grew from US$2.0 billion in 1980 to US$20.0 billion in 1991, overtaking textiles and garments, steel, shipping and automobiles to become the largest single export sector. With a population of just over three million, Singapore exported around US$15.0 billion in 1991, nearly as much as South Korea and more than Taiwan which exported US$12.2 billion.12

As shown below, by the early 1990s, local firms from each NIE were able to design their own electronics products, often working in partnership with buyers and foreign technology suppliers. Electronics capabilities were upgraded, narrowing the technological gap between themselves and the foreign market leaders. Some, such as Samsung Electronics of South Korea and ACER of Taiwan, overtook the market leaders in key areas such as dynamic random access memory (DRAM) semiconductors and computer peripherals. Historical evidence shows that firms progressed from simple assembly in the 1960s to more sophisticated systems requiring software and precision engineering skills in the 1980s.

(b) Phase 1: industry start-up (circa late 1950s and 1960s)

The South Korean electronics industry began with the production of vacuum tube radios in the late 1950s. Several US TNCs established wholly owned operations in the mid-1960s to assemble semiconductors using cheap local labor. They imparted little technology to South Korean companies according to Bloom (1991, pp. 8–10). By contrast, Japanese firms formed joint ventures which included technical assistance to local companies. For example, Matsushita and Sanyo provided technical assistance to Samsung and Goldstar in 1961 and 1962 to help them set up transistor radio factories. Toshiba set up a joint venture and began two major technical agreements with local electronics firms in the late 1960s.

Compared with exporting US companies, Japanese firms tended to view the NIEs as markets for final electrical and electronic products and as customers for Japanese made components. Except for very simple products, Japanese companies used joint ventures much more extensively than US firms, partly to gain entry into local markets. Japanese firms were also keen to use East Asian companies as contract manufacturers. At this stage the Japanese could not foresee the emergence of competitors in the region and, as is still often the case, they were able to control the supply of key components to local NIE manufacturers and partner companies. By contrast, US firms saw the Asian NIEs largely as manufacturing centers for exports based on low labor costs. US firms either invested in wholly owned subsidiaries or found contract manufacturers for simple components and products. Philips, the largest European investor, formed wholly owned subsidiaries in several East Asian counties initially to supply the local market and then to export.

The largest South Korean producer, Samsung Electronics, began as a joint venture with Sanyo of Japan in 1969, when it sent 106 employees to Sanyo and NEC for training in the production of radios, television sets and simple components. Under joint ventures with Sanyo, NEC and Sumitomo of Japan, Samsung was able to absorb foreign technology for a variety of consumer goods and components (Koh, 1992, p. 23). Joint ventures benefited both Japanese and South Korean firms, leading to long-term partnerships. South Korean firms offered the TNCs advantages of low-cost labor, management, engineering and overheads, as wages and other costs rose in Japan. South Korean latecomers provided a source of rapid, low cost capacity expansion.

Like South Korea, Taiwan, Singapore and Hong Kong began with the assembly of simple consumer goods (mostly transistor radios and black and white televisions) and semiconductors in the late 1950s and early 1960s. In 1963 Sanyo formed a joint venture with a Taiwanese importer of its goods, initiating the first Taiwanese production of white goods, air conditioning products and audio electronics. In 1966 Philips (of the Netherlands) set up a plant in the Kaosung free-trade zone in Taiwan to assemble resistors, capacitors and simple semiconductor components. Then in 1970, it began producing black and white televisions. RCA, a US firm, began producing memory circuits in 1969 and black and white televisions and monitors for re-export back to the United States in 1971. Other foreign investors in Taiwan included Sanyo, Matsushita, Orison, Sony, Sharp and Hitachi from Japan, and General Instruments and Texas Instruments (TI) from the United States. Local firms provided subcontracting services to some of these firms. In addition, Taiwanese managers, engineers and technicians were trained within the companies, generating an important human resource for the future.

In Hong Kong, the first companies to enter were Japanese, searching for cheap labor in the late 1950s to assemble transistor radios and other consumer goods. Following suit, by the mid-1960s almost every major US producer of consumer electronics and semiconductors conducted assembly in Hong Kong. They were attracted by low-cost labor, engineering and management. In 1959 Champagne Engineering Corporation became Hong Kong’s first local electronics manufacturer when it began making transistor
Philips began its commercial activities in 1951 with efficient air and sea ports. TI and SGS (of Italy) entered radios in the early 1960s, diversifying into private foreign technical and management skills. Taiwan and Hong Kong relied on buyers for technical number of specialist parts suppliers worldwide. Large industry relied almost exclusively on foreign TNCs. purchasing the necessary inputs from the growing garment manufacturers who had arrived from the Mainland in the 1950s.

Unlike the other dragons, Singapore's electronics industry relied almost exclusively on foreign TNCs. Philips began its commercial activities in 1951 with a trading office of four staff. It began making transistor radios in the early 1960s, diversifying into private branch exchange during the late 1960s. Many other US and Japanese firms entered during the 1970s to assemble electronics, attracted by the low labor costs and the efficient air and sea ports. TI and SGS (of Italy) entered Singapore in 1969 to assemble and test semiconductors.

During the start-up phase, foreign companies acted as examples for many local firms. They help initiate the first electronics ventures and started up the export industries in the NIEs. They also began training local engineers and technicians, transferring valuable foreign technical and management skills.

(c) Phase 2: take-off of simple manufactured goods (circa 1970s)

Phase 2 saw the take-off of relatively simple manufactured goods and components in each country. During the 1970s, latecomers learned to manufacture many of the new product innovations generated in the West and Japan. Often the entry route was by starting as an assembler of simple products and subsystems, purchasing the necessary inputs from the growing number of specialist parts suppliers worldwide. Large numbers of foreign TNCs and buyers entered Asian markets to buy low-cost consumer goods. New product lines included color televisions, digital watches, calculators, push-button telephones and television video games. Some local firms mastered the production technology for these goods, although many in South Korea, Taiwan and Hong Kong relied on buyers for technical assistance and market outlets. In Singapore, the TNCs dominated the electronics industry.

In South Korea several large Japanese TNCs had set up wholly owned subsidiaries during the 1970s (including Sanyo and NEC). By 1976 around 50% of South Korean electronics output was produced in foreign and jointly owned factories, mainly with Japanese and US firms (Bloom, 1991, p. 10). During this phase, the large South Korean conglomerates (or chaebol) strengthened their connections with Japanese electronics producers.

During the early 1970s, Samsung and Goldstar acquired technology mainly through licensing and subcontracting arrangements with Japanese firms. Even at this early stage, however, selective in-house R&D was used to help master production techniques and to reverse engineer products. In microwave ovens, in 1977 Samsung began a painstaking trial-and-error effort to master foreign technology and to win its first international orders, gradually learning technology from its major buyer and partner, GE of the United States (Magaziner and Patinkin, 1989). By the late 1980s Samsung had become one of the world's largest microwave oven producers. In 1977, although there were no television stations in South Korea which could broadcast in color. Samsung's engineers gathered together color television sets from GE, RCA, Hitachi and other leading companies to help them design their own model for export.

In 1976 Philips began producing color televisions in its Taiwanese facility in Kaosiung. RCA began to transfer metal oxide semiconductor (MOS) technology to firms in Taiwan through the government's Industrial Technology Research Institute (ITRI). Sanyo's joint venture began making televisions in Taiwan in 1969 and, later, video cassette recorders.

In the early 1970s, IBM and other large US TNCs began purchasing large quantities of low-cost computer subassemblies and components from several Taiwanese firms. Later in the 1970s, new local firms jumped in at the (then) state-of-the-art. The best-known example is ACER which was established under the name Multitech International Corporation in 1976 with 11 engineers. By 1987 ACER's sales reached US$331.0 million and by the early 1990s, sales exceeded US$1.0 billion per annum.

In Hong Kong, during the mid-1970s successive waves of local firms entered the consumer electronics industry mainly to supply the US market. By 1982 there were more than 1,200 local firms making calculators, computer parts, digital watches, videogames and other consumer goods. Seventy-seven percent of these were small companies, employing less than 50 persons. As in the other dragons, the electronics industry gave rise to a large supporting industry in plastic moldings, metal plating, metal working and parts.

(d) Phase 3: take-off of professional electronics (circa 1980s)

Phase 3, which took place through the 1980s, saw the rapid growth of professional electronics including computers, computer peripherals and telecommunications equipment, as well as the start-up of design and manufacture of semiconductors. The dragons consolidated their expertise in manufacturing and the electronics industry grew rapidly in each country. In the second half of the 1980s, local companies expanded their exports of high-quality precision engineering products such as hard disk drives, color display terminals, personal computers (PCs) and peripherals, video graphic adaptors, television monitors, camcorders, cameras, color terminals as well as semiconductors.
The Singapore Government encouraged foreign investment, believing that the local entrepreneurial base was too weak to lead electronics development. Process capabilities and to a limited extent design skills, were acquired mostly within TNC subsidiaries. By contrast, in Taiwan and the other dragons, local firms gained larger shares of production, improved their manufacturing skills and introduced their own designs for low-end goods. In South Korea employment in foreign subsidiaries fell by one-third during 1976-85, despite a 50% overall increase in employment in electronics (Bloom, 1991, p. 9). With the rise of South Korean firms, Japanese firms withdrew from South Korea. In 1980 Matsushita pulled out of its joint venture with Anam Electric. Sanyo withdrew from its joint venture with Samsung in 1983. NEC withdrew from its venture with Goldstar Electric in 1987. According to Bloom (1991, p. 9) Japanese firms left because government measures including the withdrawal of the special tax benefits to investors.

In Taiwan, the production value of computing and related goods overtook consumer goods in the 1980s. By 1990 the output value of computer goods was US$6.1 billion compared with US$2.3 billion for consumer electronics (O'Connor and Wang, 1992, p. 42 and p. 54). IBM, Wang and Hitachi expanded their local offices to purchase very large quantities of computers and peripherals from the local companies which surged into the growing market. By the mid to late 1980s, wages had risen in Taiwan and the country's factor advantage shifted from low cost labor to low cost, high quality engineering. TNCs increased their purchasing of keyboards, television monitors, printed circuit boards and printers. As in the other three NIEs, Taiwanese production shifted to more complex, professional equipment. This required new sills in precision engineering, electromechanical interfacing and product design. The growth in electronics led to an expansion of the supply chain of plastic molders, tool and die firms, precision machining shops, assembly subcontractors and electroplating companies.

In Singapore, as in the other NIEs, consumer goods' technology became more complex during the 1980s. Foreign TNCs began making products closer to the introduction phase of the product life cycle. Philips upgraded its Singapore facilities, adding hi-fi audio equipment, color televisions, compact disc players, new tuners and precision tools to its product range. By 1991, Philips Singapore employed around 6,100 people in five separate factories. AT&T began making high-end cordless telephones in 1986. By 1990 the local consumer electronics division had become AT&T's world center for new product design. Several TNCs began using automated facilities which extended out to local OEM suppliers. Partly as a result of its large supply of high-quality engineering, rival US disk drive producers, including Seagate, Conner and Maxtor clustered together in Singapore, also attracting material and technology input suppliers. In 1991 Singapore produced around half of the world's hard disk drives (roughly US$4.1 billion). Conner's Singapore plant became the world center for advanced manufacturing, in charge of transferring technology to Scotland and Malaysia.

During the 1980s, semiconductor process and design capabilities were assimilated within latecomer firms in the region. South Korea became a major supplier of DRAMs. In Taiwan, at least five companies began fabricating semiconductors. Philips, for example, began a joint venture with the Taiwanese Government in 1987 to form the Taiwanese Semiconductor Manufacturing Corporation to make specialist circuits for local design firms. In the third phase, local firms and their supporting industries grew more technologically capable in several areas of advanced electronics production.

(e) Phase 4: (the 1990s) toward advanced electronics and information technology

Since the late 1980s local firms have attempted to move from electronics to information technology systems, involving complex software, semiconductors and telecommunications. Nevertheless, while the larger and more successful latecomers may have narrowed the gap, most still remain well behind the technology frontier set by the international leaders and dependent on their natural competitors for key components and market outlets under OEM arrangements. While it is not possible here to assess the average progress of the latecomers, some specific examples serve to illustrate their status, strengths and weaknesses as of the early 1990s.

In July 1990 Samsung's engineers presented samples of the 16 megabit DRAM to conferences in the United States, ahead of Japanese and US market leaders and well in advance of European followers. In 10 years or so the company had caught up in one of the most challenging areas of chip manufacture. By 1992 South Korean firms had a 12% share of the world market for memory chips, including 19.7% of the four megabit DRAM market. Samsung was ranked fifth among the world's DRAM producers and first in one of four megabit DRAMS. In addition, the South Korean firms Goldstar Electron and Hyundai Electronics Industries were 12th and 13th in the world DRAM market in 1992.

In order to overcome their traditional dependency on OEM and licensing, South Korean latecomers stepped up in their in-house R&D spending, acquired overseas high-technology firms and formed technology partnerships with leading foreign companies. After setting up a semiconductor research facility in Silicon Valley in 1985, Samsung acquired Harris Microwave Semiconductor in 1993.

It is important to note, however, that the R&D efforts of South Korean firms have been mostly at the applied end of the near-market development, targeted at improving manufacturing technology and, to a lesser extent, developing their own designs of electronics products. As yet there has been little medium or long-term research aimed at producing products new-to-the-world or extending the boundaries of knowledge in the basic research fields of electronics and information technology. Similarly, the purpose of most of the chaebols' foreign investments has been to locate closer to the markets they serve, to monitor and acquire US technology and to enable final markets to guide incremental product and process developments.

One of Taiwan's leading computer makers, ACER, developed the first Chinese operating system and contributed its own four, eight and 16-bit and 32-bit PCs. It came second in the world with the 32-bit PC, ahead of IBM and just behind Compaq and was the first equipment world with the 32-bit PC, allowing the customer to upgrade the computer by plugging in a new more powerful microprocessor unit. By 1990 the company employed around 500 R&D staff. In 1991 it formed a joint venture with TI (partly funded by the Taiwanese Government) to produce DRAMs within Taiwan. In 1993 Taiwan surpassed Britain to become the fifth largest worldwide integrated circuit producer, with sales of around US$1.8 billion (Electronics, February 14, 1994, p. 9).

Again, however, while firms such as ACER may have succeeded in narrowing the technology gap in several areas and become leaders in some products and processes, even the most impressive latecomers have only succeeded in a limited number of areas. ACER, for example, still relied on OEM/ODM for a large proportion of its sales in 1993. In 1992, ACER pulled back from own-brand investments to concentrate more on OEM/ODM after sustaining heavy losses during the PC market downturn.

In Hong Kong, many firms learned to design consumer and industrial electronics. Varitronix, with a turnover of US$45.0 million in 1992, produced customized liquid crystal displays for use in Mercedes-Benz cars, miniature terminals and other electronics products. It began as a spin off from the Chinese University of Hong Kong and by 1992 had a joint technology partnership with GEC of the United Kingdom. Porro Technologies exported its own brand of workstations to Australia and the Pacific Rim. Other firms designed fax machines, cordless telephones and small screen color televisions.

Despite some impressive advances, many latecomers still suffered from significant weaknesses in the early 1990s. Only a small minority approached the technology frontier and contributed new product innovations. Most could not be described as information or high technology producers. They still relied on the manufacture of relatively simple, low-end consumer and industrial electronics. Even large firms such as Samsung depended on OEM for much of their consumer goods sales. In Taiwan and Hong Kong, despite the growth of design skills, OEM and joint ventures still accounted for a large proportion of total electronics output. In Taiwan OEM accounted for around 43% of production in computers and related goods in 1989 (III, 1191, pp. 39–43). The largest Taiwanese electronics firm, Tatung, exported around half of its output of color televisions and PCs under OEM in 1991.

Although latecomer advantages progressed from low-cost labor to precision engineering, the R&D capabilities of most firms were well behind that of the Japanese and US market leaders. With the exception of a few large South Korean and Taiwanese companies, most were still too small to fund extensive design or R&D. Among Hong Kong's latecomers 80% of electronics producers employed less than 50 staff.

Partly as a result of extensive OEM arrangements, latecomers were heavily dependent on Japan, and to a lesser extent the United States, for technology, components, machinery and capital goods. In 1990 the four NIEs imported around US$57.0 billion worth of goods from Japan, largely made up of machinery, capital goods and components (Fortune, October 7, 1991, p. 158). Each dragon had a negative trade balance with Japan throughout the 1980s, usually balanced out by a trade surplus with the United States and Europe (Chaponniere, 1992, p. 73). Despite their notable export records, trade deficits were common to the NIEs. In 1990 South Korea, Hong Kong and Singapore had overall trade deficits, while Taiwan had only a tiny surplus. In 1991 South Korean firms imported around US$21.0 billion worth of high technology industrial goods from Japan, resulting in a trade deficit with Japan of US$8.8 billion. Similarly, Taiwan's deficit with Japan reached US$9.7 billion in 1991 (Business Week, May 11, 1992, pp. 24–25).

The chaebol were especially dependent on licensing for semiconductors and key components. Samsung was the only chaebol to have developed its own DRAM technology. Goldstar relied on licensing in technology from Hitachi for basic tour and 16-megabit DRAMs. Hyundai also relied on licensing. Samsung, with its large R&D facility, had yet to achieve export market success in complex chips (e.g.,
Overseas acquisitions/equity investments
Foreign and local buyers
Licensing
Strategic partnerships for technology

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Table 1. Mechanisms of foreign technology acquisition in electronics

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<td>Foreign direct investment (FDI)</td>
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<td>Foreign and local buyers</td>
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<td>Overseas acquisitions/equity investments</td>
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<td>Strategic partnerships for technology</td>
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4. MECHANISMS OF TECHNOLOGY ACQUISITION AND MARKET ENTRY

Latecomer learning of foreign technology has become embedded in a variety of institutional channels which usually involve foreign firms in contractual arrangements in return for a payment or a particular service, such as low-cost production. These channels, presented in Table 1, evolved through time as latecomers sought to acquire complex technologies and to compete nearer the technology frontier. The channels, some of which overlap, apply to lesser or greater extents to each of the dragons. Together, they enabled latecomers to acquire technology and enter export markets. As section 5 shows, subcontracting and OEM channels allowed latecomer technological learning to be focused on export market needs.

FDI and joint ventures were an important starting point for electronics, sparking off new export lines and leading to subcontracting and OEM. As Schive (1990) and Fok (1991) show, foreign firms acted as demonstrators for local firms to imitate and some assisted local firms to grow through subcontracting and licensing agreements. Many hired and trained locals in their subsidiaries. While the overall contribution of FDI to capital formation in South Korea and Taiwan was small (James, 1990, p. 11; Dahlman and Sananikone, 1990, p. 73), it accounted for a disproportionately large share of electronics exports and employment. In Taiwan, as Schive (1990) shows, the TNCs gave rise to a Schumpeterian process of imitation and swarming on the part of local firms. In some cases, TNCs trained local firms to supply goods under subcontracting relationships. Several latecomer companies gained direct access to training and engineering support under joint ventures, including Samsung Electronics and Tatung of Taiwan.

Under licensing arrangements latecomers pay for the right to manufacture products usually for the local market and the TNC transfers the necessary technology. Generally, licensing requires more technical capacity than a joint venture, where often the senior partner trains the latecomer to manufacture. In Taiwan, during 1952–88 the government approved more than 3,000 licensing agreements (mostly in electronics), many including formal technology transfer clauses (Dahlman and Sananikone, 1990, p. 78).

Foreign and local buyers were also an important source of technology and market information in the NIEs. Hone (1974) shows that many local firms initially sold their goods to large buying houses from Japan and the United States. Foreign buyers often placed orders for 60% to 100% of the annual capacity of exporters in sectors such as clothing, electronics and plastics. The Japanese buyers (e.g., Mitsubishi, Mitsui, Marubei-Ida and Nichimen) located in the NIEs to purchase cheap goods as wages rose in Japan in the early 1960s. During the late 1960s they purchased more than US$1.4 billion per annum of low-cost East Asian manufactured goods, 75% of which were sold to the United States. This led to a stream of Japanese manufacturers to Taiwan, South Korea and Singapore. Many US retail companies (e.g., J. C. Penney, Macy’s, Bloomingdales, Marcus, and Sears Roebuck) followed suit (Hone, 1974, p. 149).

The buyers enabled many latercomers to expand their production capacity and to obtain credit against guaranteed forward export orders. Wortzel and Wortzel (1981) show how some NIE exporters progressed from passively selling low-cost production capacity to actively promoting their services to new buyers and setting up marketing offices at home and abroad. Foreign buyers assisted latecomers into export markets and supplied technology in various forms. Often from local offices, they provided latecomers with information on product designs as well as advice on quality and cost accounting procedures. The largest buyers visited factories frequently and supervised the start-up of new operations. Some assisted with the purchase of essential materials, capital goods and components.

A study by Rhee, Ross-Larson and Pursell (1984) shows that around 50% of firms in South Korea (from a sample of 113) benefited directly from buyers through plant visits by foreign engineers and visits by Koreans to overseas factories. The buyers provided local companies with blueprints and specifications, information on competing goods, production tech-
techniques as well as feedback on design, quality and performance. About 75% of firms received assistance with product design, style, and detailed specifications. In electronics, US retail chains and importers were the most important buyers during the 1970s in South Korea. Buyers helped the latecomers to overcome their distance from the advanced markets and foreign sources of technology.

OEM, a specific form of subcontracting, evolved out of the joint operations of buyers and latecomer suppliers and became the most important channel for export marketing during the 1980s. Under OEM, the latecomer produces a finished product to the precise specification of a foreign TNC. The foreign firm then markets the product under its own brand name using its own distribution channels (thereby capturing the post-manufacturing value-added), enabling the latecomer to circumvent the need for investing in marketing and distribution. OEM often involves the foreign partner in the selection of capital equipment and the training of managers, engineers and technicians as well as advice on production, financing and management. In South Korea, OEM is sometimes linked to licensing deals. Successful OEM arrangements often involve a close long-term technological relationship between partner companies, because the TNC depends on the quality, delivery and price of the final output.

OEM is also to be contrasted with ODM (own design and manufacture). The nature and complexity of the OEM system evolved considerably during the early-1980s. According to companies interviewed, many of the electronic systems purchased under OEM were designed and specified, as well as manufactured, by the local firm, rather than the TNC. In 1988 and 1989 this system began to be called ODM in Taiwan. Under ODM the latecomer carries out some or all of the product design and process tasks needed to produce a good according to a general design layout supplied by the foreign buyer or TNC. In some cases the buyer cooperates with the latecomer on the design. In others the buyer is presented with a range of finished products to choose from, defined and designed by the latecomer firms with its own knowledge of the international market. The goods are then sold under the TNC’s or buyer’s brand name as in OEM. ODM signifies the internalization of system design skills, and sometimes complex production technologies and component design abilities on the part of the latecomer.

ODM offers a mechanism for latecomer firms to capture more of the design value-added while still avoiding the risk of launching own-brand products and the costs of investing in foreign marketing and distribution channels. Under early forms of OEM, the latecomer would be confined to value-added related to assembly services. Under ODM the local company could add value in production engineering, design for manufacture and product design itself. ODM indicates an advance in technological competence, although it applied mainly to incremental (follower) designs, rather than leadership product innovations based on R&D.

The OEM/ODM system, however, has several disadvantages. Strategically, the latecomer partner is often subordinated to the decisions of the buyer, and often dependent on the foreign company for technology and components as well as market channels. The TNC will often impose restrictions on the sales activities of latecomer supplier. Without their own distribution outlets, the post-manufacturing value-added is limited. Moreover, OEM and ODM make it difficult for local companies to build up the international brand images needed for high quality goods.

Despite the problems inherent with OEM/ODM, it would be wrong to underestimate the importance of the system. It facilitated rapid industrial growth in electronics and permitted the assimilation of technology. In some cases the more restrictive clauses on OEM and licensing can be renegotiated. For example, marketing restrictions on mature products are often set aside so that South Korean firms can sell directly into third countries. The system allows many companies to achieve economies of scale in production and, in some cases, justifies investments in automation technology. For their part, foreign TNCs continue to benefit from low-cost capacity expansion, enabling rival TNCs to compete with each other. OEM/ODM therefore endures a mutually valued arrangement.

Alongside the formal mechanisms for technology transfer many informal channels exist. These include the hiring of foreign engineers and the recruiting of locals trained in foreign TNCs. Many East Asian engineers went abroad for training in foreign companies, universities, colleges and R&D institutes. As Dahlman and Sananikone (1990) show for Taiwan, informal sources of technology included the copying of products, reverse engineering and the widespread training of foreign engineers abroad. The flow of technically trained Taiwanese returning to Taiwan rose from around 250 in 1985, to 750 in 1989 to more than 1000 in 1991 (official statistics, cited in Business Week, November 30, 1992, p. 76).

As latecomer firms grew in size and competence, overseas investments became another means of acquiring foreign technology. Companies such as Samsung and Hyundai purchased several high technology firms to acquire skilled engineers and equipment. Strategic partnerships (i.e., joint ventures on a more equal footing) also enabled latecomers to enhance their technological capabilities by developing a new product or process jointly with a foreign company.

To sum up, each of the foreign technology channels in Table 1 were exploited by latecomer firms to learn skills and overcome barriers to entry into export markets. Most of the mechanisms were dual purpose, providing access to markets and to technologies. As the case studies below show, latecomers worked to couple technological and market opportunities, using market
signals as a focusing device for technological learning. Over three decades or so this coupling process has resulted a substantial, if largely incremental innovative capacity on the part of many latecomers.

5. CASE EXAMPLES OF LATECOMER TECHNOLOGICAL LEARNING

This section uses four case studies, one from each NIE, to illustrate typical technology strategies and learning paths of individual firms. The purpose is to provide qualitative insights into company-level learning and market entry in electronics. Each case looks at the origin of the company, technological milestones, learning mechanisms, channels of technology and links between market and technology, showing how these changed through time.23

(a) The case of Anam Industrial of South Korea

Anam Industrial, although the largest chip packaging company in the world, is almost unknown in the West. The company carries out subcontract semiconductor assembly and testing for large, mostly, US firms. Packaging, one of the many steps involved in chip production, involves encapsulating a tiny integrated circuit with a protective plastic or ceramic coating. Today, it is a highly complex, automated activity with a variety of processes and packages (including plastic dual-in-line with 28 to 84 leads, or pins). In 1990 so-called quad, flat packages with 64 to 208 leads were introduced as mainstream technologies. In 1993 Anam assembled around 3,000 types of chips including many leading edge products.

(i) Origin and start up

Anam began as a bicycle producer in 1956. In 1968 it became the first South Korean firm to enter the chip packaging business. The chairman made the decision to diversify after witnessing the nearby operations of US chip firms. After unsuccessfully trying to sell packaging services direct to TNC subsidiaries, in 1969 he instructed his son (studying at MIT) to sell directly to parent firms in the United States under a new marketing company called Amkor (later changed to Anam/Amkor). The main competitive resource available to Anam at that time was low-cost unskilled and semi-skilled labor and local knowledge of business practices, management and labor. In 1970, Anam’s first full year of operation, it exported around US$0.2 million worth of semiconductors.

(ii) Milestones and achievements

Anam’s export grew steadily to US$180.0 million in 1980, to US$500.0 million in 1984, to US$1.2 billion in 1990, to around US$1.8 billion in 1992. By 1991 it had exported an accumulated total of US$10.0 billion, mostly through Amkor in the United States. By 1993 it controlled around 40% of the world subcontract chip assembly market. It became the first South Korean company to produce color TVs locally through a licensing arrangement with Matsushita of Japan in 1973. During the 1970s and 1980s, Anam added audio equipment, watches, electric switches and precision instruments to its portfolio. In 1987 it began semiconductor design activities.

In 1993 the company employed around 6,000 staff, of which 4,800 were located in South Korea. As wages and land prices rose at home and the won appreciated, some production was relocated abroad. In 1989 it purchased a packaging plant in the Philippines from the US firm AMD. This plant was used to assemble relatively simple, mature products transferred out of the parent plant, using the comparatively low-cost labor in the Philippines.

By 1993 Anam/Amkor had marketing operations in the US, Europe, Japan and Hong Kong. The Santa Clara Amkor branch office was its largest overseas sales center. The offices gathered technical information on future packaging needs and some worked jointly with customers. Anam’s worldwide customers numbered more than 200, mostly in the United States.

(iii) Phase 1: learning the art of assembly

According to senior engineers, learning within the company could be divided into four main phases. The first phase, 1968–80, involved learning the art of assembly. This was a long slow period of absorbing and mastering the relatively simple techniques of manual, then semi-automated assembly. Initially, the company began by importing wafers from TI and RCA in the United States, packaging them in the ROK and then reexporting back to the United States. The first products were simple transistors and discrete devices. By 1978, the company had progressed to the assembly and testing of small-scale integrated circuits.

During this phase very little technological know-how was required. Major US clients provided help with the factory layout, assembly machinery, engineering back-up, detailed specifications and materials. The early assembly equipment was mainly depreciated machinery shipped from America. The clients despatched engineers once or twice a year to help with the setting up and running of new operations. Specifications were generally based on the US customers’ detailed requirements, as in the OEM system. During the first phase Anam sold subcontract labor-intensive assembly services, requiring little advanced engineering and virtually no R&D.

(iv) Phase 2: learning process engineering skills

The second phase, 1980–85, involved learning the engineering process skills needed for increasingly complex manufacturing processes. Some in-house
process engineering work began in 1980 with the assistance of US clients. The latter were keen to ensure high standards of quality, productivity and delivery. During 1982 and 1983 the chip industry boomed and many US firms were unable to meet the demand for their components. To meet an increasingly sophisticated and diverse demand, Anam invested in joint engineering work with larger US customers and in its own engineering facilities.

These initial forays into process engineering culminated in 1984 when Anam’s Engineering R&D (ERD) department was initiated. Rather than white collar R&D, its main function was to oversee in-house engineering back-up for manufacturing within the factory and to introduce automation of several packaging and testing tasks. Again the US clients assisted in order to ensure quality. An engineering expert from TI advised on the establishment of the department as well as its operational objectives and structure.

The ERD addressed three sets of technical issues: engineering for new packages, which involved working with customers on lead frames and substrates; improving, maintaining and adapting assembly equipment, which required joint working with suppliers on wafer mount and handling technology; and the installation, use and modification of precision machinery (e.g., the equipment used for producing molds and dies). Above all, the ERD was concerned to improve and maintain Anam’s core manufacturing processes.

(v) Phase 3: the switch to locally initiated learning

The third phase occurred over a short period, between 1985–88. It involved a subtle but important switch from customer-pull to supplier-push technological development (Anam’s terms). This marked a shift from catch-up learning to innovation centered on incremental improvements to production processes. The third phase also concerned Anam’s products (chip packages). Responding to the rising complexity of demand, Anam took the initiative by offering its own specifications to customers. In many cases, the buyer’s role changed from one of providing all the detailed specifications to that of outlining a general layout of requirements.

In most mainstream products, Anam increasingly worked to client specification with little or no backup from the US firms. Foreign engineering assistance was still supplied however, for some of the most advanced and complex packages. This switch was analogous to the move from OEM to ODM described in Section 4, reflecting the latecomer internalization of some incremental design skills.

In relatively mature processes, customers ceased to provide support for Anam’s processes as in-house engineers took over these tasks. More engineers were hired and some were promoted to senior positions. The ERD took on the task of buying production equipment, and installing and adapting it as needed. Engineers became competent in modifying and operating a wide array of complex packaging equipment. Incremental process changes occurred as engineers made many minor improvements to equipment, benefiting productivity and quality.

Several factors forced the pace of learning, notably the increase in client numbers and profit opportunities, the diversity of customer needs and the importance of improving quality to maximize exports. These factors led Anam’s efforts to internalize more engineering operations. Continued dependency on outside suppliers would have slowed export growth by causing delays, imposing higher costs, restricting diversification and dulling the reputation of the firm. The company’s engineering competence improved the image of Anam as an independent, high-quality supplier of high technology services.

(vi) Phase 4: toward product innovation capabilities

Phase 4, which began around 1988, saw an upgrading of in-house product innovation capabilities coupled with a deepening of process skills. After 1988, Anam’s ERD increased its development work on new packaging and test processes with several leading chip makers, including IBM, TI and Motorola. Anam adopted a deliberate technology strategy to exploit its position as a focused world specialist in packaging. To meet future demands, the company worked more on leading-edge assembly techniques, applied software modeling for chip package designs, and developed new packages and processes. Again, US firms worked jointly with Anam on specific projects to ensure quality and delivery.

By 1993 Anam had achieved fairly advanced packaging capabilities, extending to products such as ASICs and RISC chips, including 256-pin counts as standard and 504-pin counts for special batches. It operated the latest high-volume automated packaging and testing facilities under a computer-integrated manufacturing control system, utilizing statistical process control techniques. The company had built competences in the computer modeling of processes, data analysis techniques for product reliability and failure analysis. State-of-the-art chip-testing services were available and integrated-circuit design services for customers were provided.

The company continued to work with capital equipment suppliers from Japan and the United States to modify systems to meet new specifications. Most of Anam’s mature production (e.g., 14, 16 and 20-pin counts) were transferred abroad to Anam Philippines Inc. In 1993 the company employed more than 200 engineers, of which 70 were centralized in the ERD laboratory. The director of the ERD had a doctorate in physics from a US university where he had worked as a professor. Although the engineering contingent was small by international standards, it provided Anam with competent, highly focused, customer-oriented capabilities.
(vii) Interpreting the Anam case

The case of Anam illustrates latecomer advance from assembly, to minor process innovation to incremental product innovation along a fairly well-established chip packaging trajectory. By the early 1990s, Anam was able to extend the boundaries of its chosen technological niche. Over the years it had acquired the skills to focus its technology efforts precisely on the needs of its export market customers.

Anam’s progress indicates not only catch-up learning, but also innovation capacity building in at least three directions. First, minor process innovations enabled Anam to gain productivity and quality improvements. Modifying equipment and adapting machinery gradually yielded productivity and quality benefits. Second, Anam learned to conduct minor product innovations. Like other East Asian latecomers, Anam learned by relating products to processes, reverse engineering and working closely on product specifications with its clients. Third, innovation was evident in the company’s organizational structure and orientation. It became the first major company worldwide to offer packaging only services to customers. Exploiting export market needs, led to Anam’s strategic positioning as the world’s largest chip packaging firm.

Another central feature of Anam’s learning were foreign channels of technology. Throughout each phase of learning, subcontract linkages were exploited by Anam to its advantage and to the benefit of the export customers. The most recent phase involved strategic partnerships with foreign TNCs. The latter were conducted on a more equal footing compared with the partnership of the 1970s. Through the foreign TNCs, export markets provided the focusing device for technological learning and innovation.

A final feature of Anam was its enduring latecomer orientation. Although Anam had risen from bicycle maker to the largest world semiconductor packager in 25 years, it remained a latecomer, depending on foreign firms for technology and market outlets. Some of the companies it relied upon were its natural competitors, themselves in the business of chip packaging (e.g., IBM). In R&D terms, the company’s facilities were small in scale and limited mostly to relatively short-term requirements. In marketing terms, its brand image remained weak compared with other US$2.0 billion corporations. Despite its achievements, Anam was still a latecomer in structure, strategy and orientation.

(b) The case of RJP of Hong Kong

(i) Origin and achievements

RJP, a consumer electronics manufacturer, was founded in May 1971 with nine employees. By 1993 annual sales were in the order of HK$400.0 million (US$57.0 million). The firm employed around 3,200 staff (mostly located in China) and had sales and service centers in Los Angeles, Chicago and Vancouver (40% of sales were to the United States). Its product-range included pocket and desk top diaries, pagers, translators, electronic games, keyboards, karaoke machines, calculators, simple medical electronics, car radio cassette players and watches. By 1993 the firm had acquired electronic systems and chip design capabilities. It had narrowed the technology gap in consumer electronics and had launched several own brand products.

The company’s founders were three brothers, one a trader and one an engineer. They began the company by investing family savings and some borrowed money from backers in Hong Kong. In 1973 RJP began to assemble calculators, an important activity until 1979. Table 2 shows the evolution of key product lines and technological milestones. In 1975 it began using microprocessors in small volumes to develop simple electronic toys in house.

(ii) Learning under OEM and ODM

Like many East Asian firms, RJP began manufacturing simple goods under OEM and gradually moved on to increasingly complex electronics. By the early 1990s it had diversified into the lower end of the computer industry offering own designed databanks and pocket computers. Under OEM, the firm learned how to manufacture a variety of goods. J. C. Penney, the US retail outlet, assisted with basic manufacturing know-how in the early stages by sending quality control engineers to help ensure quality, delivery and productivity. Other local and foreign traders based in Hong Kong provided export outlets and market and technical information.

Table 2. Key products and technological milestones*

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971</td>
<td>company start up, production of light dimmer switches</td>
</tr>
<tr>
<td>1973</td>
<td>entered calculator production</td>
</tr>
<tr>
<td>1975</td>
<td>began making digital watches and TV games</td>
</tr>
<tr>
<td>1975</td>
<td>began use of microprocessors (MPUs)</td>
</tr>
<tr>
<td>1977</td>
<td>started joint chip design work with TI for radio controlled toys</td>
</tr>
<tr>
<td>1979</td>
<td>entered educational toy market</td>
</tr>
<tr>
<td>1981</td>
<td>1986 — designed electronic rulers, using MPUs</td>
</tr>
<tr>
<td>1986</td>
<td>began production of medical devices</td>
</tr>
<tr>
<td>1986</td>
<td>designed pocket computer for manufacture (OEM and ODM)</td>
</tr>
<tr>
<td>1991</td>
<td>expanded audio range, added Karaoke systems, electronic diaries and directories</td>
</tr>
<tr>
<td>1993</td>
<td>designed palmtop computer</td>
</tr>
<tr>
<td>1993</td>
<td>product range reached 200 entries</td>
</tr>
</tbody>
</table>

* Milestones are in italics.
Source: company interviews.
Through time, RJP increased its contribution to the overall design content of most of its product lines. It experimented with new product models and worked closely with several US chip suppliers. TI's sales engineers were an important source of chip design technology. TI's motive was to expand component sales and to buy finished calculators under OEM. With increasing design demands, RJP hired in some of TI's engineers. RJP's relationship with TI endured and deepened as both companies gained from the relationship.

By the mid-1980s the company controlled the design of most of its key product lines and had registered several patents in the United States. As a small company, most technology investments were for near-market engineering needs, rather than R&D. In 1993 a little research had begun, mostly for future designs for databanks, musical key boards and educational goods. The number of engineers in Hong Kong rose from 20 in 1986 to 40 in 1993 as a result of general business expansion and increasing technical demands.

(iii) **RJP's move to ODM and OBM**

During the 1980s RJP progressed from OEM to ODM to OBM (own-brand manufacture). OBM occurs where the firm sells goods under its own brand name, capturing more of the post-production added value. During 1981–86 RJP designed a combined ruler/calculator/digital watch which proved to be a cash cow. After the demand for rulers slowed in 1986 the firm diversified into pocket databanks. This remained a large revenue earner, along with electronic games and toys. In 1986 RJP designed and launched its own-brand electronic diaries and pocket computers in response to expected market demand. This was followed in 1993 by an OBM palmtop computer as RJP attempted to diversify into the low end of the professional electronics market.

OEM business frequently imposed restrictions on RJP. OEM deals often entailed an exclusive agreement with one buyer, limiting other market opportunities. On the positive side, some OEM/ODM clients (often small US firms) came with new product ideas to RJP to design and develop experimental systems. This was an important means by which RJP focused its learning on export market needs. OEM and then ODM forced RJP to continuously improve product quality as single shipments of substandard goods or delays could lead to the permanent loss of a buyer to another Hong Kong competitor.

(iv) **Transfer of OEM to China**

RJP's two main offices in Hong Kong dealt with finance, marketing and sales. All manufacturing operations had been transferred to China to take advantage of low-cost labor and land. Twelve separate manufacturing facilities were operated in Schenzen and Guangdong. Like many other small Hong Kong producers RJP had learned to couple overseas market demand with the supply of low cost production capacity in China. In order to benefit from the opening up of China, RJP set up joint ventures with several Mainland enterprises including Softron, Zhenbao, Starmate Garden and Hunan Wire. Softron is a software engineering firm established by professors from the faculty of Guangdong University. Their low-cost software engineers enabled RJP to carry out more engineering work than would otherwise have been possible in Hong Kong. Zhenbao operated a large retail network throughout China, promising future growth for RJP.

(v) **RJP: interpretation**

As with the case of Anam, RJP's learning evolved with market expansion. RJP closed much of the technology gap with activities progressing from mature to earlier stages of the product life cycle, from simple manufacture to complex design work, and from assembly tasks to process engineering and development. During the 1980s RJP internalized systems abilities, chip-design capabilities and was able to offer new product innovations under ODM and OBM.

Under the OEM/ODM system RJP's engineers worked hand-in-hand with foreign buyers and components suppliers. Through time the company expanded its competences and introduced minor product designs and incremental changes to processes. Like Anam, RJP embarked on purposeful innovative capacity building in order to pursue profit opportunities in export markets. RJP remained dependent on OEM for some of its sales and to that extent was still a late-comer. With OBM, however, it began the transition from latecomer to follower, competing with improved design, and by adding new proprietary features.

(c) **The case of Wearnes Hollingsworth Group of Singapore**

(i) **Origin and expansion**

In 1992, the Wearnes Hollingsworth Group was the largest locally owned manufacturer of PCs, peripherals and components in Singapore. A new division (Wearnes Computer Systems) operated more than 50 service centers in Pacific-Asia and Europe, which sold Wearnes own-brand computers and provided after-sales support. Wearnes began as an Australian-owned distributor of British cars. In the 1930s a majority share of the company was purchased by the Overseas Chinese Banking Corporation. The company began the assembly of simple connectors for electronics systems in the mid-1960s. Metal stamping, plastic injection molding and plating began in the mid-1970s. The Group began making PCs in a subsidiary company, Wearnes Automation (WA), in 1983. It also entered
hard disk drives, floppy disk drives, add-on cards and expanded its range of electromechanical components including connectors.

(ii) Learning under OEM

In PCs, Wearnes built up a reputation as a high quality, fast delivery OEM supplier of computer systems, printed circuit boards and components. Several senior managers were hired in from TNC subsidiaries in Singapore. Most junior engineers and technicians were recruited from local universities and polytechnics. Under OEM, the TNC buyers supplied Wearnes with technical specifications for given products. For Wearnes, OEM sales enabled economies of scale in production and in the purchase of materials and key inputs (e.g. microprocessors). OEM volumes also justified investments in automation technology, enabling improved productivity and quality. Under OEM the firm learned the rigors of high-quality, fast turnaround production.

To manufacture PCs and related products, the company upgraded its existing skills in high precision electromechanical technologies. Engineers (up to MSc level) were recruited from local universities. In general, MBAs were not recruited unless they also held engineering degrees. In the early 1990s, Wearnes still saw its main technological strengths in high-quality engineering applied to electromechanical and electronic interfacing tasks, in connector manufacture, chip packaging, plastic molding and electroplating, rather than software or R&D.

Gradually, the firm developed its own in-house designs and brand name sales in PCs, progressing beyond OEM. Nevertheless, as with RJP, Wearnes continued OEM alongside OBM as part of its business strategy for expansion. For example, in 1992, the firm greatly expanded its OEM business by entering into a long-term arrangement to supply IBM, offering profit, market prestige and further scale advantages.

(iii) Learning by acquisition and hiring

To organize the expansion into PCs, a director was hired from a relatively small Singaporean electronics venture, previously engaged in printed circuit board manufacture. This individual advised on the expansion into the PC business and by 1992 had become a senior member of the Board. As and when necessary, Singaporeans trained in foreign companies were searched for and recruited for specific jobs in engineering and management.

The firm also gained know-how by acquiring several small high-technology companies in the United States, including a 40% share of Advanced Logic Research, and two other chip design firms. It also purchased United Circuits (Hong Kong) in 1989 (a maker of printed circuit boards) and a chip packaging firm OMEDATA (Indonesia) in 1986. Some of the acquisitions proved costly and difficult to integrate technologically. Through its US investments, however, the company acquired new chip design capabilities to add to its core electromechanical strengths. In the early 1990s, it invested an average of around 6% of its annual sales on R&D, mainly applied work oriented toward production needs.

(iv) Wearnes: interpretation

The case of Wearnes confirms the path dependent nature of latecomer technological learning. Software and R&D capabilities were added to electromechanical, precision engineering and basic manufacturing skills, rather than replacing them. Although there was a tendency to move from simple to complex activities through time, the firm acquired competences and deployed them as and when necessary to maximize sales and profit, according to the company’s broader strategy. As Wearnes progressed from subcontract assembly of connectors, to OEM, ODM and OBM in computers, capabilities were learned with respect to technology, organization, management and marketing. As a latecomer, OEM remained an important option for the company, despite its product design abilities and OBM aspirations.

(d) The case of Microelectronics Technology Inc. (MTI) of Taiwan

(i) Origin and development

MTI, a supplier of integrated circuits for telecommunications (mainly microwave systems) and components for direct broadcast satellite, digital radio and maritime communications systems, started in 1983 with eight founders, all from Silicon Valley. By 1992 turnover was around US$100.0 million. Around 700 staff were employed in Taiwan and a further 100 in the United States. Each of the founders had worked for US corporations, including Hewlett-Packard (HP) TRW and Harris. They returned to Taiwan in response to profit and market growth opportunities. The government offered MTI a package of tax incentives, loans and the science park facilities at Hsinchu Science Based Industrial Park.

The skills and US connections of the founders meant that sourcing and acquiring technology presented little problem to the company. MTI began with a small line of integrated circuits for microwave products, mainly niche sectors such as receiving dishes for satellites and communication systems for ships and aircraft. The first export orders were produced under OEM for American manufacturers who then supplied satellite TV broadcasters in the United States. The early products were labor-intensive and the main attraction to the US buyers was low cost. Most component inputs were imported from the United States and Japan. The directors learned new technological
and marketing skills while working with the larger OEM clients in North America.

(ii) From OEM to OBM

With expansion, MTI's output became progressively automated. Manufacturing skills were accumulated under OEM and by the mid-1980s the firm began to introduce its own product innovations, some for ODM, others OBM. In 1986 MTI developed a new special low-noise amplifier for the direct broadcast satellite field. This was followed by the world's smallest and lightest INMARSAT standard-A terminal, for maritime communications. Several other incremental product innovations helped the company to grow and improve its image in the United States.

In 1992 around 90% of products were exported, of which more than half were still supplied under OEM/ODM. Regarding, OBM strategy, the company's size preempted direct competition with major suppliers. It also preempted large-scale R&D spending on major innovations. Small size enabled it to be sufficiently agile however, to respond quickly to fast changing niches and new market demands.

(iii) Technological advance

As of 1992, MTI's manufacturing capabilities were comparable with those of leading firms worldwide. Facilities included CAD/CAM workstations for designing microwave circuits, clean room facilities, precision equipment for mask aligning, automatic dic-

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* No stages or linearity implied, but a general tendency to catch up cumulatively, through time with capabilities building systematically upon each other.

† Although it is useful to distinguish between process and product technology for analytical purposes, in practice the two are often inextricably entwined.

Figure 1. Latecomer firms — export-led learning from behind the technology frontier.
ing systems and so on. In some cases the equipment was the latest available. Of the 700 employees, around 130 were engineers with degrees, including some PhDs. Of the engineers 50% were locally educated and most of the rest were US trained.

In order to carry out engineering and development work with its major clients, MTI had set up two subsidiaries, one in the United States and one in Canada. MTI’s customer base in 1992 included many of the founders’ former employers (e.g., HP, Digital Microwave Corporation and Hughes Network Systems). Newer clients included STC Marine and BT in the United Kingdom. Like other Taiwanese high technology start-ups, MTI’s strategy was to increase OBM where possible.

(iv) MTI: interpretation

The case of MTI confirms other case findings. Links with export clients assisted technology sourcing and learning. A combination of internal efforts and joint projects generated user-pull innovation. Innovation was of the incremental type, centered on cost process and then moving to product improvements. OEM provided a channel for export business growth and technological learning. The next section interprets the case study findings within the broader context of export development and technological advance.

6. A SUGGESTED INTERPRETATION: EXPORT-LED TECHNOLOGICAL LEARNING

Figure 1 suggests a simple framework for analyzing the nature, direction and determinants of latecomer technological learning in the NIEs. Its purpose is to locate the case material within the historical evidence of sections 2 and 3 and to generate further questions for analysis.

(a) From simple to complex learning and R&D

The left-hand vertical axis represents total electronics exports for each country. As exports take off, wages and other costs increase as a result of bottlenecks, shortages and capacity limitations. The horizontal axis represents technological accumulation through time, beginning with simple activities such as assembly and gradually toward more complex tasks such as process adaptation and eventually R&D. On the marketing side the model reflects the transition from OEM, to ODM to OBM. This cumulative view of how learning develops from simple to complex tasks is confirmed by Dahlman, Ross-Larson and Westphal (1985) who show that learning develops in sequence, shifting from production to investment to innovation capabilities. Similarly, Lall (1982) indicates how industries make the passage from elementary to intermediate to advanced learning, noting that the learning of marketing and managerial skills is also important to development.

A strict linear progression need not occur through time. R&D may begin fairly early on and there may be feedback between early and later stages. The scheme suggests however, that there is a general tendency for firms to begin with simple tasks and accumulate capabilities systematically in a path dependent, cumulative manner, with skills and knowledge gradually building on each other.

The S-shaped curve suggests that within each country there will tend to be a start-up, take-off, growth and maturation phase in electronics. The industry began in the 1950s and 1960s when TNCs and local firms entered to profit from new opportunities. As some were successful, others followed in a Schumpeterian swarming fashion, leading to a take-off during the 1970s and 1980s. Eventually, growth slows down as larger market segments (e.g., consumer electronics) mature and wages rise. There is no reason however, why the curve should follow this particular path. Swarming may begin very early. Export growth may not reach bottlenecks at any particular stage. As wages rise, the local market may begin to absorb a larger share of total production (as has occurred in South Korea and Taiwan). Moreover, firms may overcome rising cost problems by relocating production to lower cost countries such as China and Thailand, and concentrating on higher technology production at home.

(b) Implications for traditional innovation models

In Figure 1 the technology frontier is represented by the right-hand vertical axis. It is defined here simply as the position at which substantial R&D is required to generate new product or process innovations. This is a moving frontier occupied by leading firms at any given time. Through time, the latecomers gradually narrow the technology gap between themselves and the leaders. By the 1990s, some latecomers reach the frontier in at least some product lines. As in the case of Samsung in DRAMS, substantial investment in R&D are then required to compete with the international leaders. At the frontier, standard innovation models will begin to apply as R&D becomes an early and central part of the innovation process and leader and follower dynamics begin.

This scheme reverses traditional models of innovation, as these assume leadership or followership and generally place R&D at the center of innovation. For latecomers the key to competitiveness runs contrary to theories which stress R&D or place R&D at the beginning of the innovation process. R&D generally occurs (if at all) in the latter stages of a catch-up learning path which begins with simple tasks such as labor-inten-
sive assembly for established products, in line with Vernon’s (1966) life cycle model.

The model of Figure 1 should not be seen as a generalizable model of innovation, but rather a specific model which attempts to capture the historical catching up of East Asian latecomer firm in electronics. The model may well not apply to other types of industry which do not exhibit the key features of electronics, including fast growth and the possibility of an extensive division of labor across national boundaries. Electronics is a manufacturing-drive, high-throughput industry where the costs of labor, technicians and engineers play a crucial part in competitive advantage. The relevance of electronics, for example, to customized, project-based systems industries (e.g., aerospace, intelligent buildings, nuclear power equipment and flight simulators) may well be limited, as competitive advantage is seldom, if ever, based largely on volume production costs and incremental process improvements, as in electronics. In addition, as section 7 argues, the model may only have limited relevance to non-Asian developing countries, although some of the general insights are of interest.

Although R&D may not be central to latecomer firm strategies, innovation is essential for catching up to occur. Latecomer innovation focuses on engineering effort to improve production processes and reduce manufacturing costs (at least in the initial stages). Later, innovation occurs as firms learn to make incremental changes to product designs and eventually introduce their own new designs. This type of behind-the-frontier innovation enables catch-up development to occur. Continuous innovation is probably a necessary condition for latecomer firms to narrow the technology gap between themselves and market leaders. In the absence of relatively fast innovation, firms would merely keep up rather than catch up.

Latecomer innovation is triggered by profit opportunities provided by fast growing export markets. The small size of local markets forces companies to export. Firms initially compete with each other for export orders on cost and speed of delivery. Over time, they compete on quality, reliability and own-design capabilities. Local competition and imitation generate continuous process improvements and the rethinking of business and technology strategies. Channels such as OEM and subcontracting relay export market requirements directly to the latecomers.

Not all firms need to innovate in the above manner. New start-up firms may jump in at advanced levels, missing out the early stages (as MTI and ACER did in Taiwan). As the absorptive capacity of the economy increases new start-ups may by-pass earlier phases. Spin-offs from older firms, diversifications from other sectors, and new experimental start-ups will constitute the growing industrial base. There is no automatic process by which technology accumulation occurs. On the contrary, firms learn to innovate by their own efforts and investments in technology. Purposeful learning efforts are needed to assimilate foreign technology, build up new competences and catch up with market leaders.

The model suggests that process and product technology are closely linked and that feedback occurs from one to the other during the catch-up process. While early entrants tend to concentrate on assembly and absorbing basic manufacturing skills, in the later stages the distinction between product and process innovation becomes more blurred. Improving the production process often requires knowledge of product design. Similarly, improvements in product design and reliability may necessitate skills in production processes. During the 1980s, the ability to precisely specify product designs to enable manufacturing efficiency (design for manufacturability) became a key competitive factor in electronics. The locus of technological capacity of industry overall tends, however, to shift cumulatively from operational skills, to process improvements to product innovation capabilities and eventually to development and research abilities.

(c) Links between learning and the export market

In the simple model, learning occurs not only at the technological level but also at the marketing level. Firms learn to package, distribute and market their goods (Wortzel and Wortzel, 1981). Some establish marketing departments at home and then in the advanced countries. Marketing know-how enables firms to diversify their customer base and to increase their growth opportunities and, like technology, involves substantial investments in skills and organization. Ultimately, advanced latecomers establish their own brand names abroad and may advertise directly to customers.

There may not always be systematic, causal links between the stages of technology and market development. It is theoretically possible for a firm to acquire advanced technological skills but to still remain at the early stages of marketing — or vice versa. It is likely however, that latecomer firms will try and improve both their technology and marketing capabilities simultaneously in order to increase profit and market share.

In other cases there may be concrete connections between market and technology. The channels for learning technological and marketing skills may be one and the same, as with OEM/ODM. To increase sale of production capacity to key customers, joint engineering work may be needed, as shown in the case studies. Later on, to bring new products to the market, firms may need to make long-term investments in R&D.

To sum up, in the simple model, exports pull forward the technology of latecomer firms, enabling
them to overcome the lack of user-product links enjoyed by leaders and followers. Through OEM and other channels, export demand acts as a focusing device for learning and forces the pace of progress. Local competition stimulates innovation, successful exporters are imitated by more latecomers, and gradually a relocation of production to a developing economy occurs.

(d) Further questions raised

Although the model is schematic, it suggests some interesting future lines of enquiry. First, what precisely is the balance between local and foreign sources of technology? Indeed, is it possible to separate the two or, as suggested above, are they closely entwined in a symbiotic relationship, needed to create the user-pull of international markets? If foreign channels are an essential feature of fast catch-up growth, then what are the possibilities for firms operating under import-substitution regimes, or export regimes making the transition from import-substitution, as in many Latin American countries? Is it possible to catch up technologically without the pull of international demand?

Second, what are the factors which determine successful export-led technological development? Although it was outside the scope of this paper to examine the lessons from failure, examples of unsuccessful firms and failed OEM experiments could well provide insights success and failure. For instance, why should similar OEM systems stimulate fast technological catch-up in East Asia but not in the Mexican maquiladoras or the Manaus free-trade zone in Brazil?

Third, as noted in section 6 (b) above, one difficulty with the focus on electronics, is whether or not it has relevance in other industries. In other industries, such as steel and petrochemicals, different relationships and factors may determine the balance between successful local learning and final product markets. Also interesting is the way firms in leading sectors, such as electronics, forge backward linkages with local supply firms and create new support industries. Electronics may have had a demonstration effect on other sectors, given the very large scale of the industry in East Asia.

A fourth question concerns government policies. How important were direct and indirect policies in stimulating firm-level learning, if at all? Although educational policies and vocational training provided the raw human material supply for firms (Vogel, 1991; Amsden, 1989), there is very little written on the formal and informal methods by which latecomers trained employees in technology-specific skills, with the partial exception of South Korea (e.g., Koh, 1992). Similarly, although creating a stable macroeconomic environment was an important function of government (World Bank, 1993), the importance of direct interventions via technology institutes and programs is far less clear. Some authors claim these have been highly significant in certain cases, but as yet there is little research into the costs, benefits and scale of impact of policy intervention on firm-level learning in East Asia.

Fifth, regarding the future, if the above arguments are correct, then most latecomers are still distinct from followers and leaders. Although some have made the transition to follower and leader in some areas, many are highly dependent on OEM and subcontracting for access to markets and technology. Through the 1990s and into the next century a variety of strategic options face the latecomer firms. As more approach the innovation frontier, they may require new strategies to acquire technology and to overcome remaining weaknesses. They may wish to take on characteristics of followers and leaders by increasing their R&D expenditures and improving their brand image abroad. Alternatively they may wish to expand their basic OEM activities into neighboring low-cost areas. They may decide to pursue a mixture of both strategies.

The evidence suggests that there is no easy or automatic transition from latecomer to leader or follower. Indeed, East Asian electronics producers have grown extremely rapidly and successfully on the basis of subcontracting, OEM and ODM; some have retreated back to OEM/ODM after attempting to launch own-brand products and suffering heavy losses. OEM/ODM could well remain the dominant feature of industrial growth in electronics for some time to come. A transition to leadership and followership status on a broad front would require radical changes not only in the way latecomer firms operate but also in the environment in which they compete. For example, firms would have to develop strong marketing capabilities and invest heavily in creating brand images acceptable to worldwide consumers. Similarly, they would have to create a strong research culture within their companies and considerably increase their investments in basic and applied research to generate significant new innovations. Manufacturing firms would also need the support of a much stronger local capital goods sector and software industry than exists in the East Asian NIEs. The question of whether firms will seek to make the risky and costly transition, en masse, is therefore an open one, which will depend to some extent on the skills and strategies of Western and Japanese TNCs who no doubt will wish to defend their status as world leaders and followers.

7. IMPLICATIONS FOR OTHER DEVELOPING COUNTRIES

Both the model and the evidence above have important implications for other developing countries. It is important to remember however, that each econ-
Second, for second-tier East Asian countries and other developing nations wishing to generate a dynamic electronics industry, contrary to much conventional policy wisdom, East Asian latecomers did not leapfrog from one vintage of technology to another. On the contrary, the evidence shows that firms engaged in a painstaking and cumulative process of technological learning: a hard slog rather than a leapfrog. The route to advanced electronics and information technology was through a long difficult learning process, driven by the manufacture of electronic goods for export. Even at today’s relatively advanced stage, the competitive advantage of East Asia’s latecomers is low-cost, high-quality production engineering, rather than software or R&D. Although the NIEs are increasing their investments in science and advanced technology, they remain conspicuously weak compared with Japan and other OECD countries.

Also in contrast with leapfrogging, much latecomer learning took place in fields which could be described as pre-electronic, including mechanical, electromechanical and precision engineering activities. The policy implication of this finding is that to build an electronics industry, local firms require human resources trained across a range of basic craft, technician, engineering and industrial skills, rather than the software and computer-based skills normally associated with information technology. Like the NIEs, other developing countries should take very seriously the low-technology side of so-called high-technology industries. Only by developing capabilities in fields such as plastics, moldings, machinery, assembly and electromechanical interfacing, did East Asia emerge as the leading export region for electronics. This, in turn, suggests that educational policies should ensure an adequate supply of technicians and engineers in low as well as high-technology fields.

Third, while it was not possible in this paper to examine the broader economic context, many other studies show that macroeconomic stability provided an environment conducive to long-term corporate planning and investment. In order to fully exploit technological opportunities and to optimize any form of industrial development, policies toward inflation, interest rates, balance of payments and other macroeconomic essentials have to be implemented effectively. It is difficult to see how countries with accelerating inflation and constant industrial turbulence can achieve sustained, long-term industrial development of the kind witnessed in East Asia. Similarly, outward-looking, export-led policies were essential stimulants to innovation. Policies which focus primarily on local markets cannot achieve the technology pulled exercised by export markets, and felt directly by the firms examined in this paper. Only by engaging demanding users can latecomer dislocation from advanced country markets be overcome.

Fourth, while macroeconomic studies demonstrate the importance of stability, few studies deal with policies to stimulate the development of firms to overcome any corporate failure which may exist. One lesson from the East Asia experience is that a dynamic entrepreneurial base is essential for acquiring technology and exploiting new market opportunities. This corporate base cannot be taken for granted as it is in many studies of East Asian development (e.g., World Bank, 1993). The entrepreneurial base may involve locally owned firms, joint ventures and foreign subsidiaries. In Singapore, the Government believed that the local entrepreneurial base was too weak to lead industrialization and encouraged TNCs to take this role. Similarly, in Malaysia the TNCs dominated the electronics industry. In South Korea, the government built up a small number of large local firms with incentives, subsidies and targets to enable them to overcome barriers to entry in world markets. It is highly unlikely that the chaebol would have emerged spontaneously if left to market forces. In Taiwan, the government left the electronics industry largely in the hands of local overseas Chinese entrepreneurs, but in areas of high capital intensity such as semiconductors, steel, automobiles and petrochemicals intervened directly through state ownership and other means to ensure industrial development.

Fifth, while conducive macroeconomic environments and policies to overcome weaknesses in the
entrepreneurial fabric are important, they are only one side of the equation. Equally important, but rarely analyzed, are the strategies and actions of firms in overcoming barriers to entry, acquiring technology, learning to innovate and exploiting foreign market opportunities. In general, it is up to people in firms to search out and exploit market and technological opportunities as industrial growth relies upon the skills of managers, engineers, technicians and other company employees. The implication here is that a far greater understanding of the strategies and systems employed by East Asian firms is needed, and that the firm should become a far more important unit of analysis than it usually is in studies of technology and economic development. A better understanding of the factors which facilitate and restrain corporate success would assist both firms and policy makers seeking to learn from the East Asian experience.

To sum up, despite the peculiarities of the industry, electronics is the largest East Asian export sector and much can be learned from the experience of firms in the NIEs. The lessons from electronics may well apply to a wide range of other fast-growing export industries including bicycles, clothing, athletic footwear and sewing machines. The industry has led directly to the emergence of a variety of important support industries which have grown up alongside electronics. In addition to being the leading industry in the region, electronics has had a wide demonstration effect, showing to firms and policy makers alike what can be achieved. The industry is of vital interest to East Asian region and promises many useful insights for other developing nations.

8. CONCLUSION

This paper introduced the idea of the latecomer firm, a new analytical category distinct from leaders and followers, in order to describe the technological and market difficulties confronting East Asian firms and to explore how they narrowed the technological gap in electronics. Through their strategies of linking technological learning to foreign customer demand, East Asian companies generated their export achievements and brought about a geographical relocation of production to the region. Within the firms, subcontracting and OEM mechanisms were used to overcome market barriers to entry and then to assimilate process and product technologies. The needs of demanding export customers were used by firms as a focusing device for technological learning, investments and efforts.

The evidence suggests that firms progressed from learning the techniques of simple manufacturing to genuine innovation. Unlike the R&D and design-led innovation typical of leaders and followers, latecomer innovation began with incremental improvements to manufacturing processes. As competences were learned, minor innovations to product designs were made and, eventually, some new products were offered to the market. Only in the most recent phase, and only selectively, did R&D become a significant factor in the innovation efforts of the latecomers. The paper argued that intercompany organizational innovations assisted the advance of the NIEs. The OEM and subcontracting systems acted as a training school for local firms, helping them to couple export market needs with foreign technological learning. Through their catch up efforts, during the 1980s the OEM system evolved into ODM, indicating significant product design competences on the part of latecomers. As innovative organizational arrangements, new OEM/ODM channels were pioneered and exploited with foreign partners, enabling the latecomers to surmount their market and technological disadvantages.

The latecomer origin and orientation of East Asian electronics producers, pinpointed the continuing weaknesses of many firms. Only in a small number of areas had major new product innovations been generated locally. In most fields latecomers were still dependent on their natural competitors for key components, capital goods and distribution channels. Firms suffered from weak R&D capabilities and poor brand images abroad. Without stronger product innovation capabilities they will continue to rely on a mixture of catch-up, imitation-based growth and incremental innovation in electronics. Lacking R&D capabilities and a strong capital goods sector in electronics, the technological roots of the four dragons remain shallow.

It would be wrong to overstate the problems facing the latecomers within the OEM/ODM system. These difficulties almost pale into insignificance compared with the disadvantages already overcome. Local firms have built up significant technological competences and a deep understanding of international market needs. As they approach the technology frontier, some begin to forge strategic partnerships with world leaders to acquire more advanced technologies. Many have narrowed the technology gap and are poised to make further advances toward the innovation frontier. While it is impossible to predict the future, the evidence suggests that the achievements are built upon a solid historical foundation of learning. Many of the latecomers are well positioned to respond to the fast changing pace of electronics technology.
1. South Korea and Taiwan lag behind the two city states in GNP per capita. Each NIE, however, has experienced very rapid wage rates, enabling them to jump up the GNP ranking of nations. See Wade (1990, p. 35) and James (1990, p. 4) for historical achievements of the NIEs. Note that the four dragons are sometimes called tigers.

2. For the purposes of this paper the term electronics includes consumer goods, semiconductor components, computer and telecommunications equipment and other hardware. Information technology is used to describe the generic technology for controlling and storing information, including both software and hardware inputs.

3. South Korea is relatively well documented, especially in the heavy and chemical industries. Enos and Park (1989) examine petrochemicals, synthetic fibres, machinery, iron and steel. Amsden (1989) looks at automobiles, cement, shipbuilding, textiles, steel and heavy machinery. There are few studies of the technology strategies of South Korean electronics firms, or how learning proceeded in the other dragons. Jun and Kim (1990) and Bloom (1992) provide general assessments of the electronics industry in South Korea. See Ernst and O'Connor (1992) for a negative assessment of the NIEs' position in electronics. The latter study focuses on the general difficulties of competing in modern electronics, rather than the technology strategies of East Asian firms.

4. Following Schmookler (1966) and Gerstenfeld and Wortzel (1977, pp. 59–60) this paper defines innovation as a product or process new to the firm, rather than to the world or marketplace.

5. Egan and Mody (1992) examine buyer-seller links in bicycles and footwear. Again, South Korea is well covered, partly because firm is often synonymous with industry. Most studies however, take industry or government as the unit of analysis, rather than the firm.


7. Given its complex nature, learning is very difficult to research. Dodgson (1991) p. 23 defines technological learning as: "the way firms build and supplement their knowledge bases about technologies, products and processes, and develop and improve the use of the broad skills of their workforces." Firm learning, as with the learning of individuals, is difficult to observe, to accurately measure, or to distinguish from other activities. It is a qualitative, usually informal, process. It is often idiosyncratic, cumulative, dynamic and uncertain in outcome, involving both knowledge and experience. Learning is usually costly and often difficult to undertake. As Malerba (1992) shows, however, it is central to incremental technical change, firm productivity growth and to product and process improvements. From a research perspective, this paper uses case studies based on interviews with company directors and engineers to analyze how firms learned and to provide insights into the nature, extent, timing, mechanisms and determinants of learning.

8. OEM (discussed in sections 4 and 5) is a form of subcontracting where a latecomer manufactures a finished good for a buyer, often a large TNC. In the four dragons, OEM accounted for a large proportion of consumer electronics exports during the 1970s and 1980s. OEM is similar to subcontracting in semiconductors and other sectors such as bicycles and footwear (Egan and Mody, 1992). The term OEM originated in the 1950s among computer makers who used subcontractors (called the OEM) to assemble equipment for them. It was later adopted by US chip companies in the 1960s who used OEMs to assemble and test semiconductors. Since then the term has acquired a variety of meanings. Some use the term to mean the final system maker (the TNC buyer), rather than the supplier or subcontractor. To avoid confusion, in this paper OEM refers to the system by which firms cooperate in subcontracting relationships, rather than the buyer or supplier.


10. The idea of innovation leader and follower usually refers to a firm's strategy in a specific product technology. A single firm could be a leader in some areas and a follower in others. By contrast, firms from developing countries will tend to be latecomers across a broad range of product and process technologies.

11. For an analysis of follower and leader strategies see Ansoff and Stewart (1967), Porter (1985, Chapter 5) and Teece (1986). Freeman's (1974, p. 176) terms, offensive and defensive strategies, are broadly equivalent to the leadership and followership strategies of Porter and Teece. Freeman makes it clear that innovation strategies relate to specific products, so that a company may decide on a mix of strategies to follow.

12. For details see Fok (1991, pp. 257–258) for Hong Kong, Sakong (1993, p. 232) for South Korea, O'Connor and Wang (1992, p. 41) for Taiwan and EDB (1992) for Singapore (all official figures in current prices). Electronics accounted for about 40% of Singapore's total manufacturing output in 1992 and around 40% of its exports (Electronics, April 26 1993, p. 5). In South Korea electronics accounted for around 28% of total exports in 1991. These figures are not strictly comparable for definitional reasons. The Singapore figures include around 75% re-exports which is more than the other dragons (Financial Times March 29, 1993; Singapore Survey, p. 11).

13. By 1991 backward linkage firms employed around
30,000 workers in Hong Kong to add to the 64,000 or so employed in electronics manufacture (Fok, 1991, pp. 259–264). Schive (1990) shows that many backward linkages to local firms resulted from TNC investments in Taiwan.

14. For example, see the case of Wearnes Automation, section 5(c).

15. In South Korea, the chaebol have become very large and resourceful exporters of electronics. In 1992 Samsung alone exported around US$7.8 billion worth of electronics. In addition Goldstar exported US$4.8 billion and Daewoo US$2.2 billion (calculated from the Korea Economic Weekly, March 15, 1993, p. 8). Other major players in electronics include Anam with sales of US$1.2 billion, Hyundai, US$1.4 billion, and Saangyong with US$1.0 billion (company annual reports for 1992).

16. See Business Week (November 30, 1992, pp. 70–71) for a report on DRAMs.

17. Around 30% according to some reports. In 1990 OEM accounted for 70% to 80% of South Korean electronics exports (excluding semiconductors), and even more in the latest technology goods according to Electronic Business estimates (April 22, 1991, p. 59). Jun and Kim (1990, p. 22) show that OEM constituted about 50% to 60% of export of South Korean color TVs and VCRs in 1988.

18. In 1990 the six largest foreign OEM buyers in Taiwan were (in order) IBM, Philips, NEC, Epson, Hewlett Packard and NCR (III, 1991, pp. 39–43).

19. It is beyond the scope of this paper to compare their relative importance through time or across countries, or to analyze how the mechanisms relate to each other. Comparing local with foreign sources is also a difficult task as the two are inextricably entwined (as Section 5 indicates), with local efforts being essential to absorb foreign technology. Dahlman and Sannakone (1990) provide an analysis for the case of Taiwan. Schive (1990) deals in-depth with FDI in Taiwan, the support industry underpins much of the success of the latecomer exporters.

20. Egan and Mody (1992) and Forbes (December 21, 1992) show how US manufacturers and distributors purchased bicycles from Taiwan and transferred technology; eventually the Taiwanese succeeded in displacing most of their former American teachers.

21. The term ODM was first noted by Johnstone (1989, pp. 50–51). Johnstone argued that small Taiwanese firms pioneered ODM for clients with no design capability of their own (e.g., US chain stores such as Sears). Interviews for this study (e.g., Samsung Electronics, 1993) suggest however, that ODM evolved gradually out of OEM arrangements, as local companies assimilated more capabilities and offered more design services to OEM buyers to gain more business. This process occurred in South Korea and in Hong Kong, as well as in Taiwan (see the case studies in section 5).

22. In Taiwan former Bell Labs. employees formed the Taiwanese Bell Systems Alumni Association which had 120 members in 1992. Similarly in 1994 there were around 80 Bell Labs Alumni in South Korea. Hundreds of other Korean scientists and engineers had returned from Caltech, MIT and other leading US technology centers.

23. The companies are selected from 55 case studies conducted over 1992–94 (see Hobday, 1995). Although each case is special, the four firms are not untypical of the mass of less well-known latecomer firms, most of whom learned under subcontracting or OEM arrangements. The research was primarily based on interviews with company directors, senior engineers and, where possible, the founders of each company. Database searches and company reports were also used for support information. The four companies here are selected on the basis of: (a) country; (b) size; (c) period of entry; (d) electronics subsector (semiconductors, consumer goods, computing and telecommunications are covered).

24. Many other examples of organizational innovation are evident in East Asia. In Taiwan, for example, the company TSMC became the first major firm in the world to offer fabrication only services in semiconductors. The OEM and ODM systems are also example of organizational innovations, which were in part created by the latecomers.

25. Forrest (1991) provides a useful summary of simple and complex innovation models incorporating feedback loops and external factors, such as policy and the macroeconomy. Magaziner and Patinkin (1989) show how R&D began very early on in the case of Samsung in microwave production.

26. For traditional innovation models see Utterback and Abernathy (1975) and Utterback and Suarez (1993). Again, see Forrest (1991) for a critique of a range of Western innovation models. Criticisms include the assumption of linearity and the failure to include feedback loops.

27. For a comparative industry analysis for South Korea, see Kim and Lee (1987) who argue that the degree of scale and complexity in operations technology account for differences in patterns of firm behavior across sectors.

28. Fok (1991, pp. 263–264) touches on this issue for Hong Kong, showing how electronics is supported by a supply chain of (often small) firms in plastic casings, printed circuit board assembly, metal workings and parts, plating and tooling. In Taiwan, the support industry underpins much of the success of the latercomer exporters.

29. In Taiwan, ITRI helped stimulate learning in scale-intensive electronics areas such as semiconductors, but was largely absent from the OEM sector. Kim, Kim and Yoon (1992) claim that the Korean institute ETRI assisted technology development in telecommunications, though there is little analysis of firm strategies.
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EAST ASIAN LATECOMER FIRMS


